

# Transformation Cloaks for Surface Electromagnetic Waves

By

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**Abstract:** - An invisibility cloaking device for electromagnetic waves in free space is deemed fundamentally difficult, because the electromagnetic waves inside the cloak need to follow a prolonged bending path, requiring superluminal propagation—a feat potentially achievable only over an extremely narrow band. Here we show that, by switching from free-space electromagnetic waves to surface electromagnetic waves, transformation cloaks can find immediate applications without any fundamental limitations. We demonstrate a class of cloaks capable of remarkable broadband surface electromagnetic waves guidance around ultrasharp corners and bumps with no perceptible changes in amplitude and phase. This work is published in PNAS 112, 7635-7638 (2015).

**Keywords:** - Invisibility cloaking; Broadband; Surface wave

**Reference:** -

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- [2] J. B. Pendry, et al, Science 312, 1780-1782 (2006).
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[11] S. Xu, et al, Proc. Natl. Acad. Sci. USA 112, 7635-7638 (2015)



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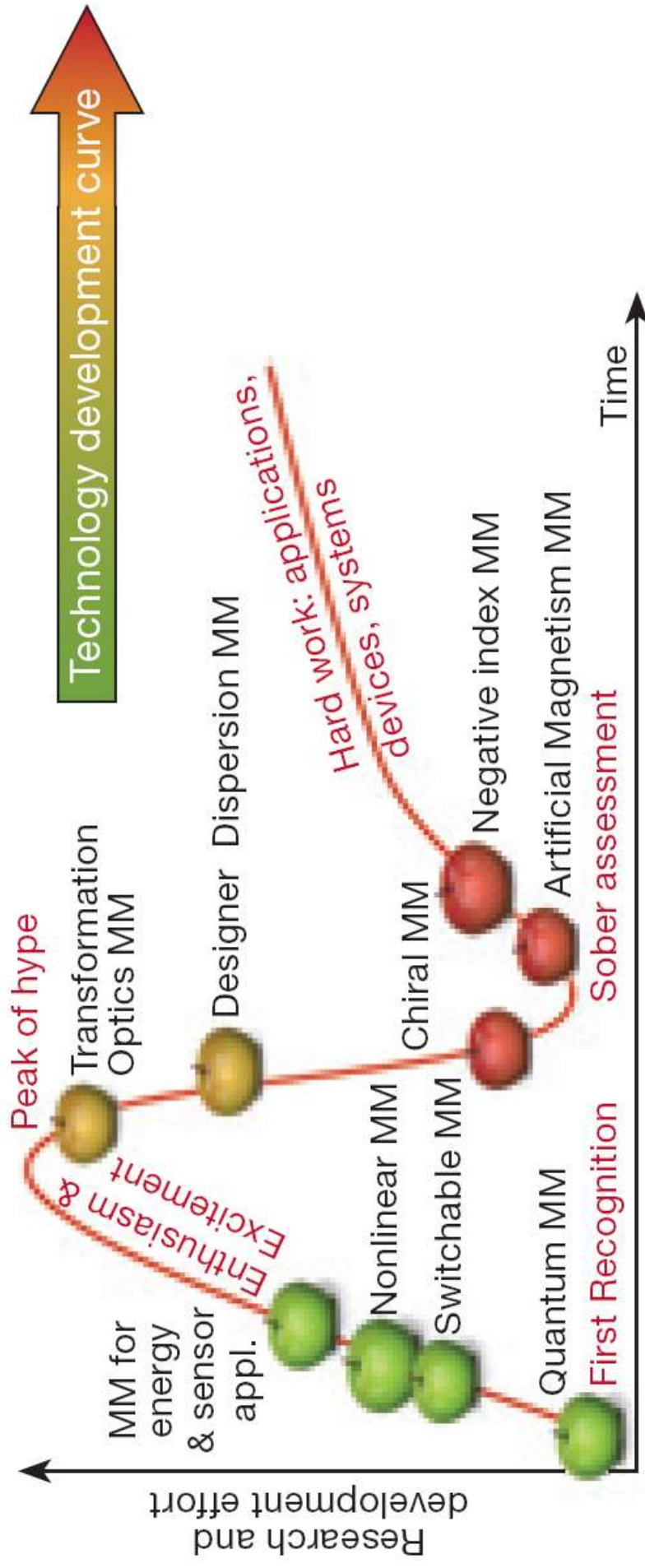
# “Metamaterials: The Next Photonic Revolution”



ORC: Optoelectronics Research Centre, University of Southampton

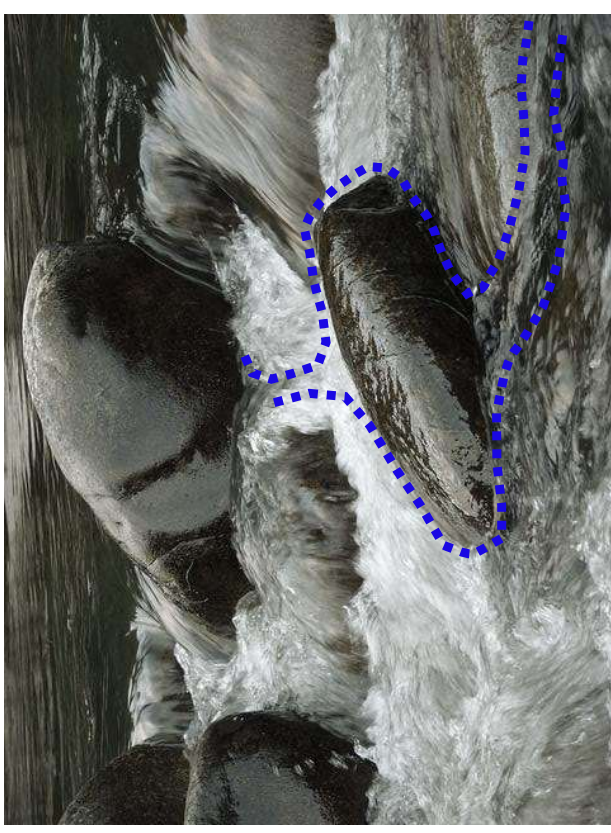
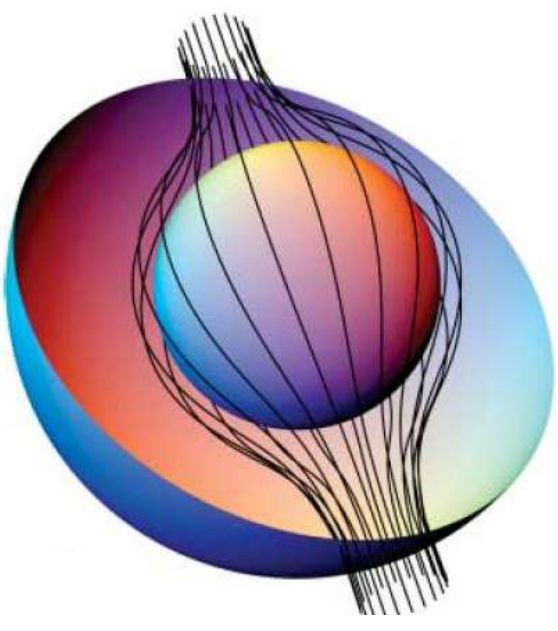
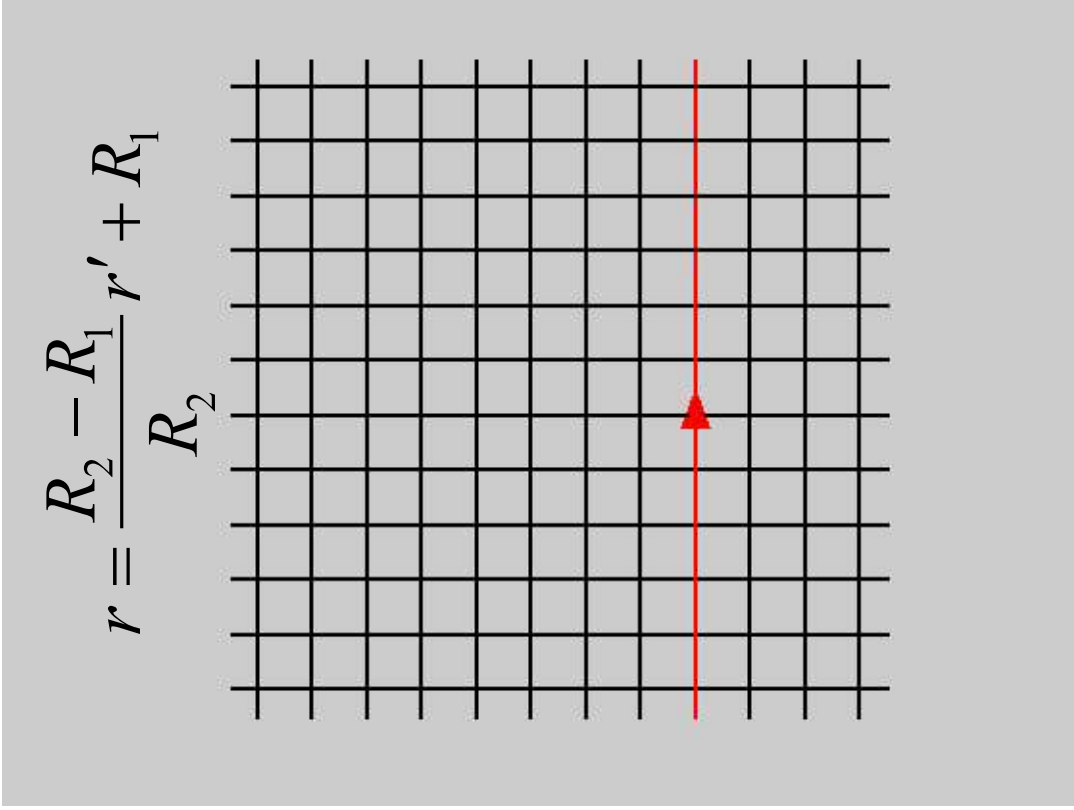
[www.nanophotonics.org.uk](http://www.nanophotonics.org.uk)

# “The road ahead for metamaterials”





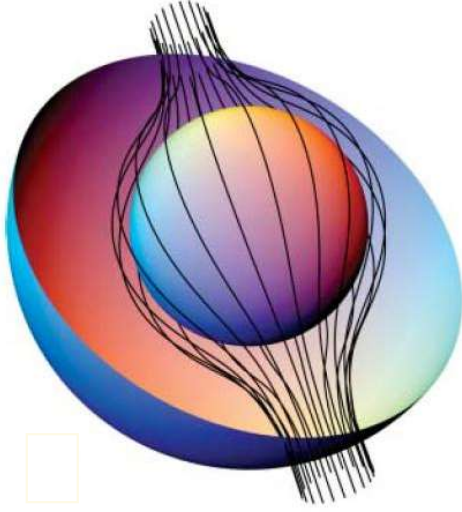
# Transformation and wave bending



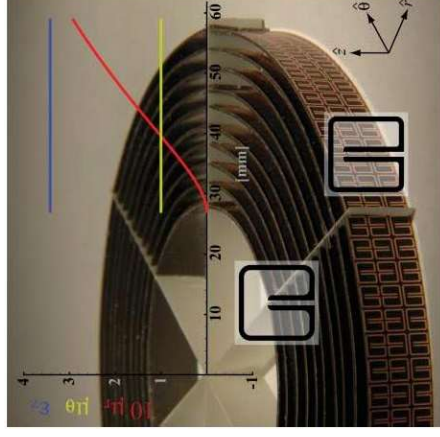
*J. B. Pendry, et al, Science 312, 1780, 2006*

# Free-space EM cloak – challenge and its origin

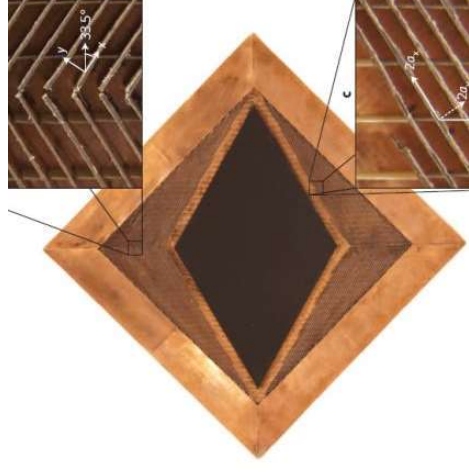
3D



2D



1D



*Science* 312, 1780 (2006)

*Science* 314, 978 (2006)

*Nature Mater.* 12, 25 (2013)

Superluminal  
propagation



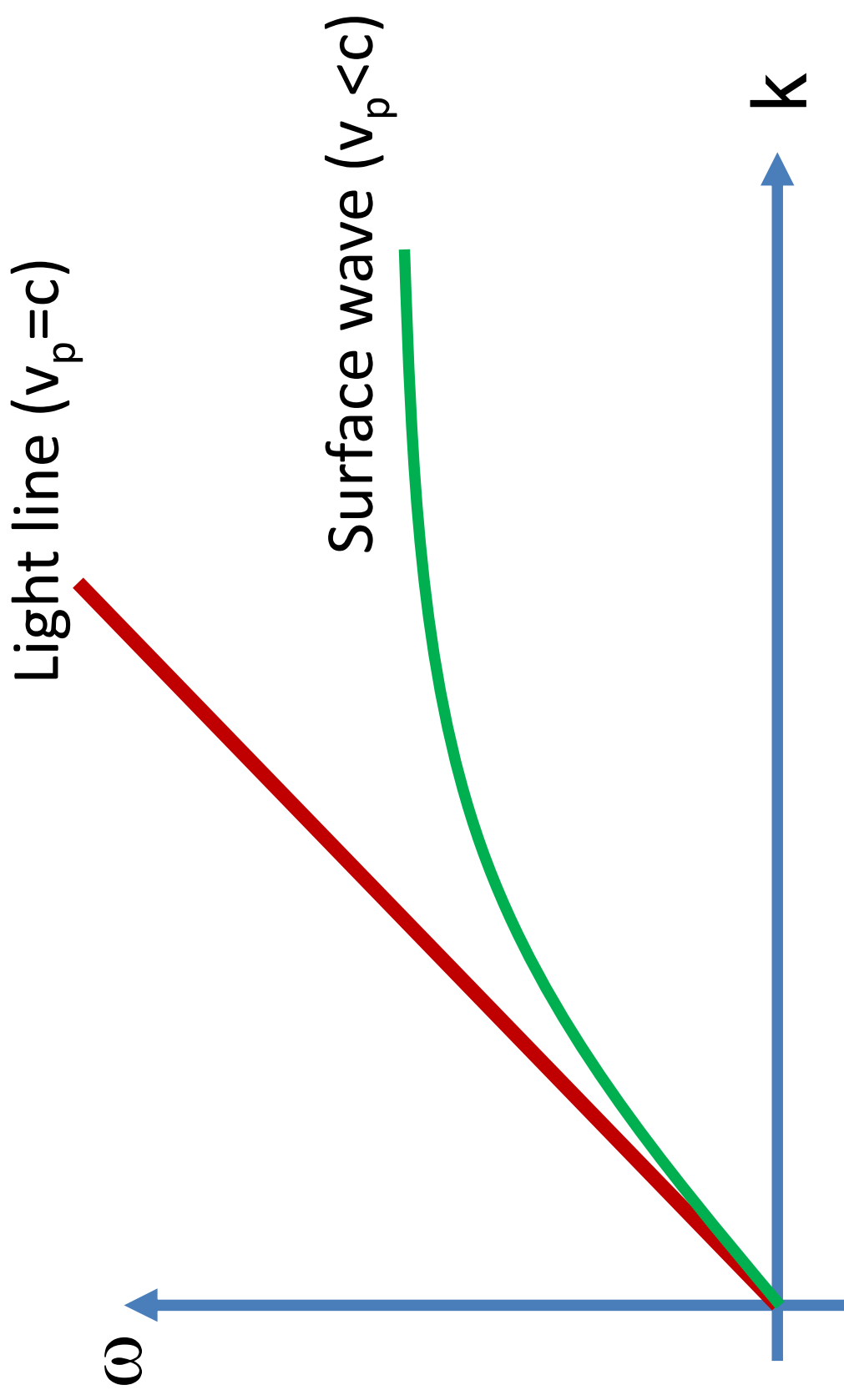
Polarization sensitive  
Narrow bandwidth



We cannot beat relativity!

# Where to go then?

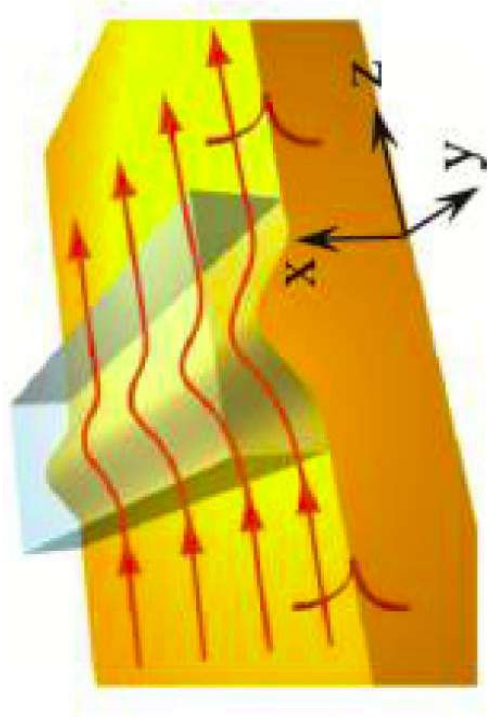
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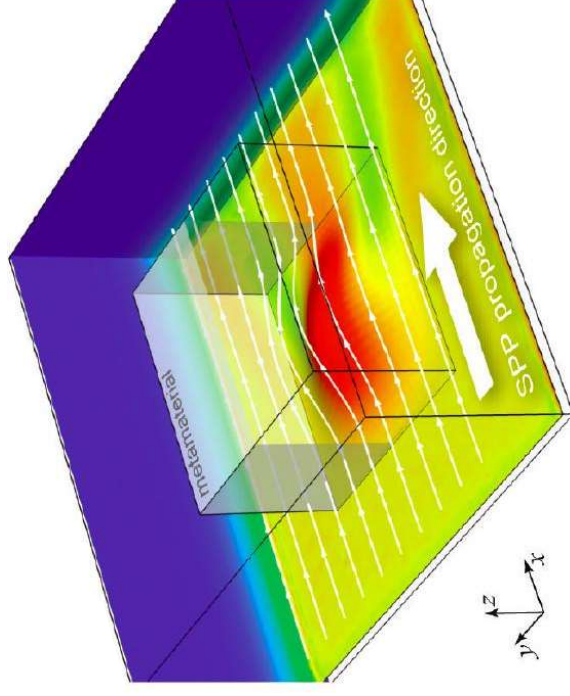


# Previous proposals

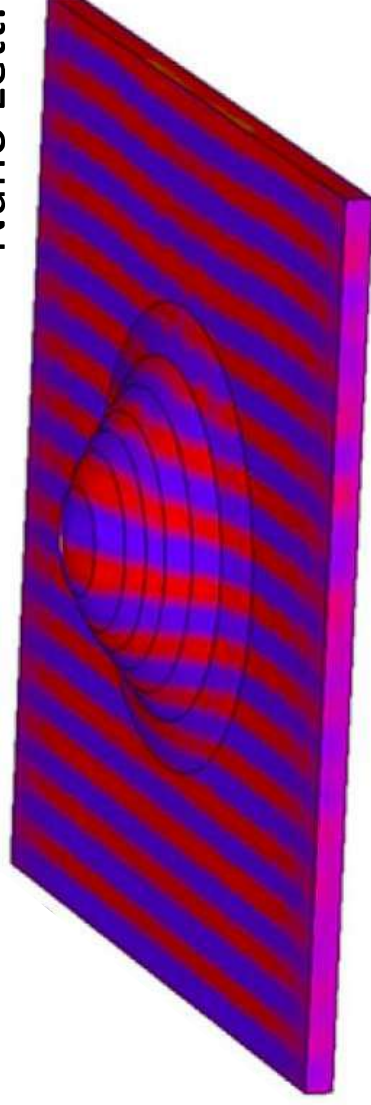
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Nano Lett. 10, 1991 (2010)



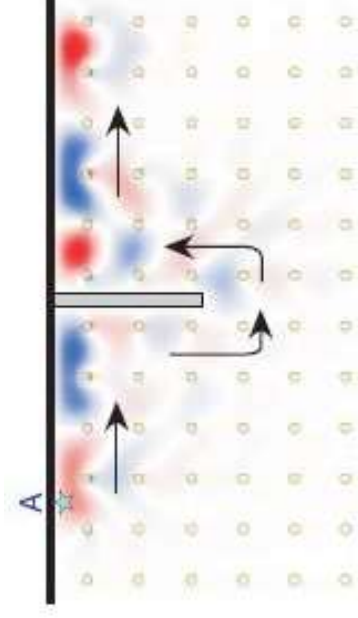
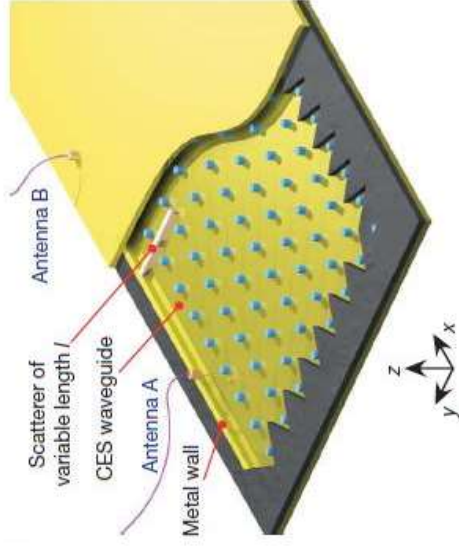
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PRL 111, 213901 (2013)

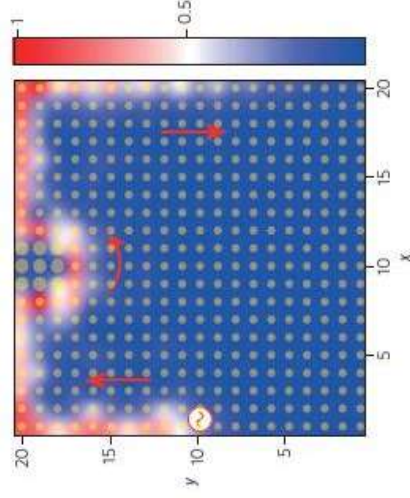
Limitation: Not applicable to sharp corners or bumps

# Topological photonic edge states

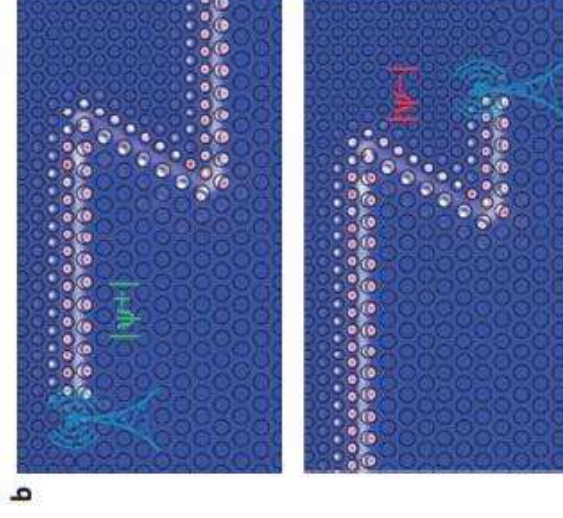


Robust transport  
through disorder

Nature 461, 772 (2009).



Nat. Pho. 6, 782 (2012).



Limitation:

1. Phase distortion
2. Narrow bandwidth

Nat. Mat. 12, 233 (2013).

# Why is it difficult?

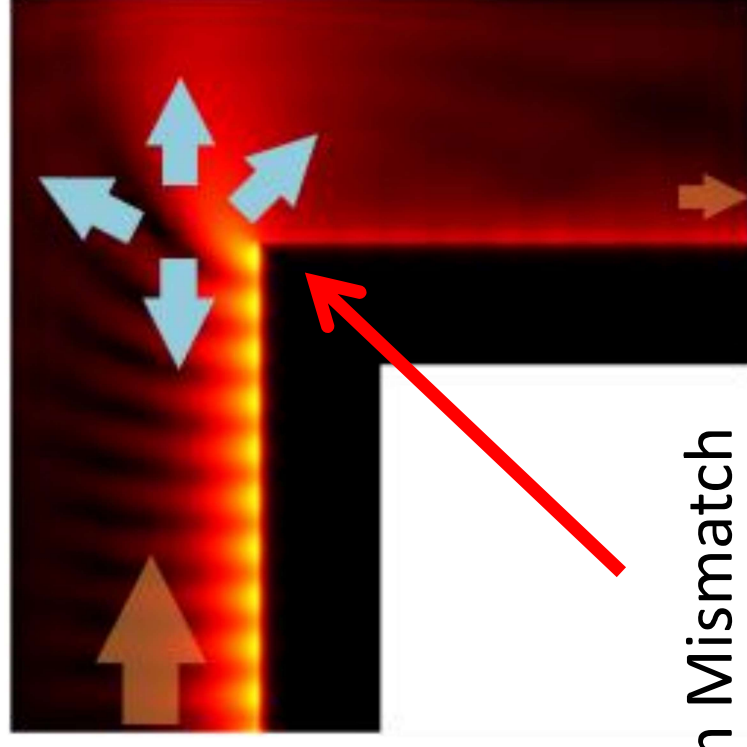
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Challenge: Scattering loss

No scattering on flat interface

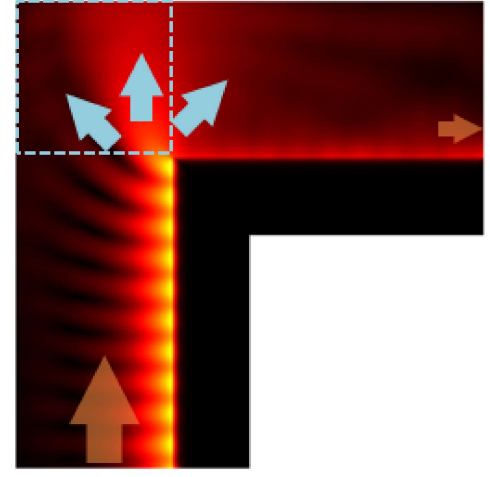
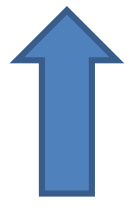
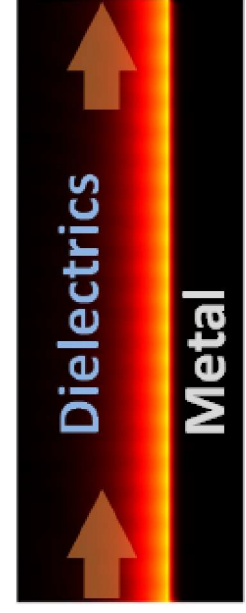
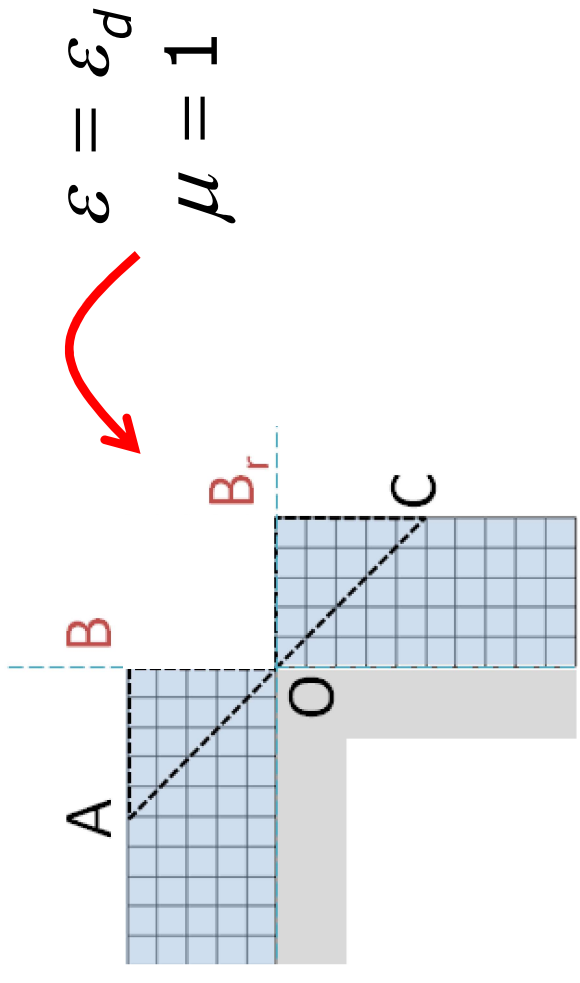
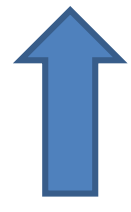
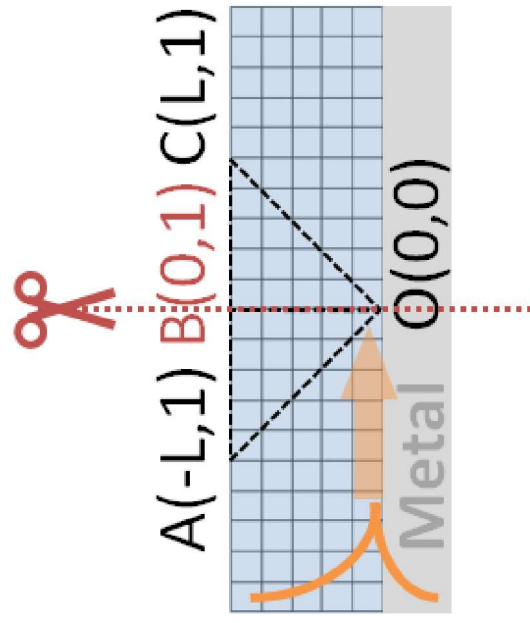


Scattering at sharp corner

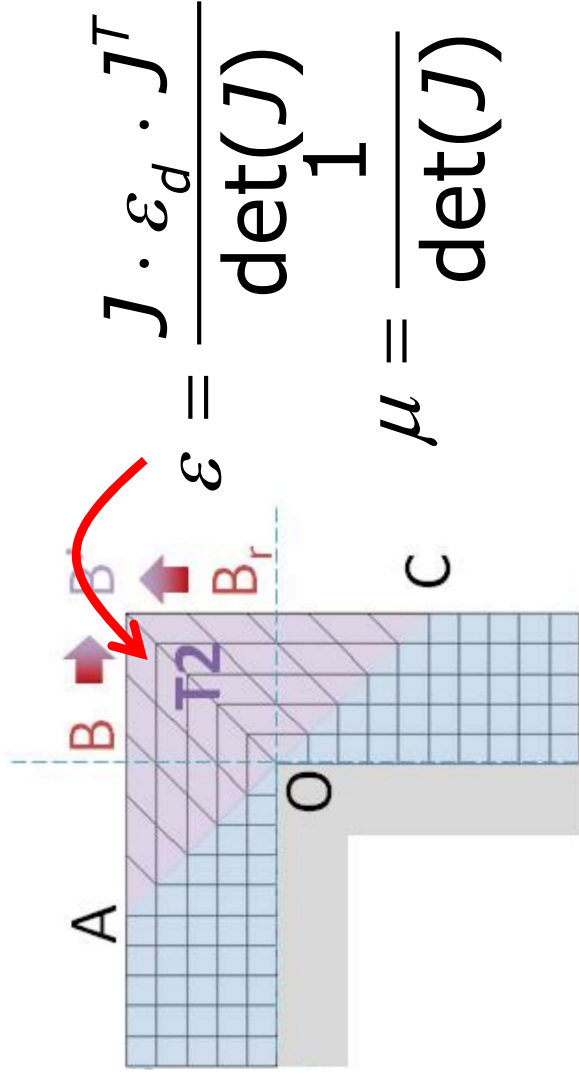
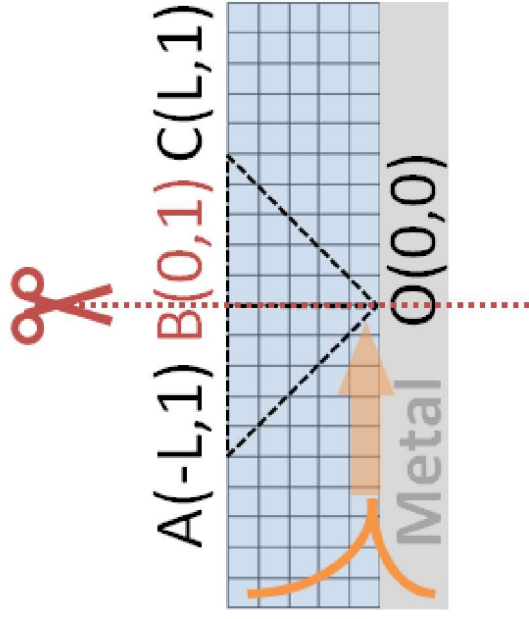


Momentum Mismatch

# How to bend surface wave?

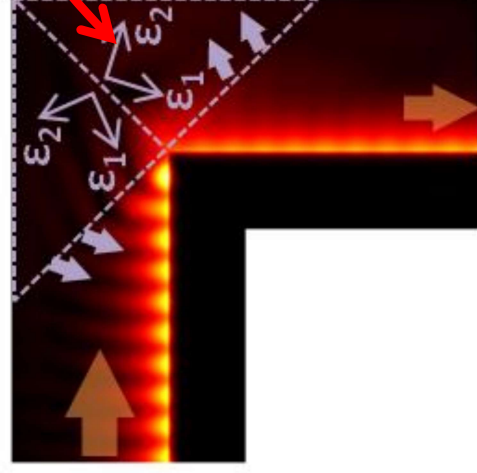


# How to bend surface wave?



$$\varepsilon = \frac{J \cdot \varepsilon_d \cdot J^T}{\det(J)}$$

$$\mu = \frac{1}{\det(J)}$$

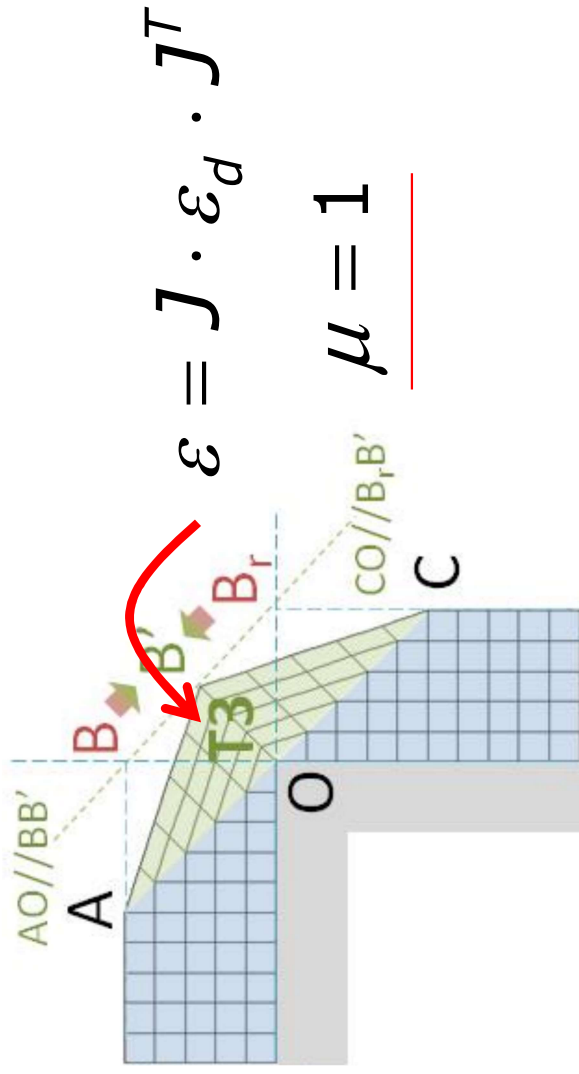
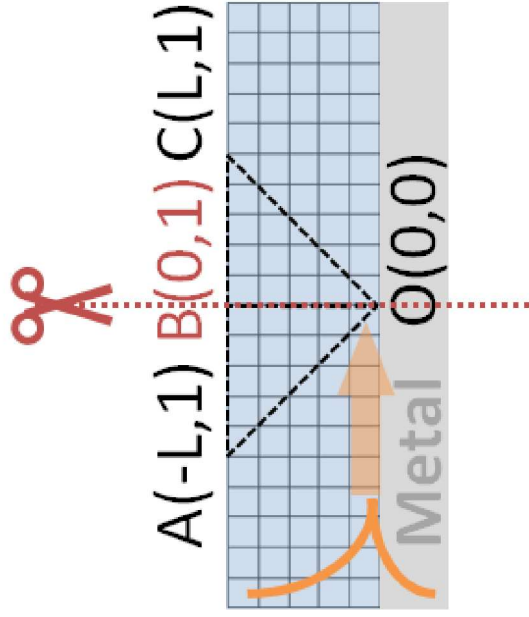


$$\varepsilon = \frac{J \cdot \varepsilon_d \cdot J^T}{\det(J)^2}$$

$$\mu = 1$$



# How to bend surface wave?



Dielectrics

Metal

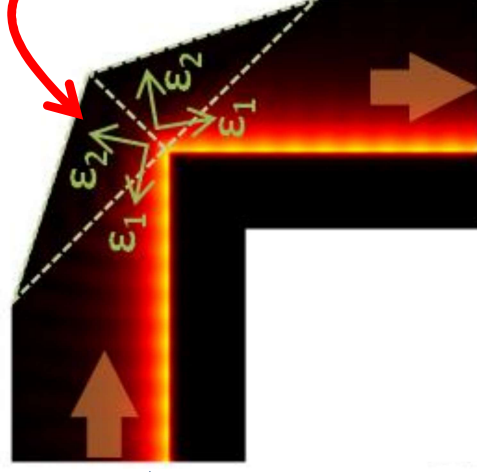


Multilayer of

foam/ceramic at microwave

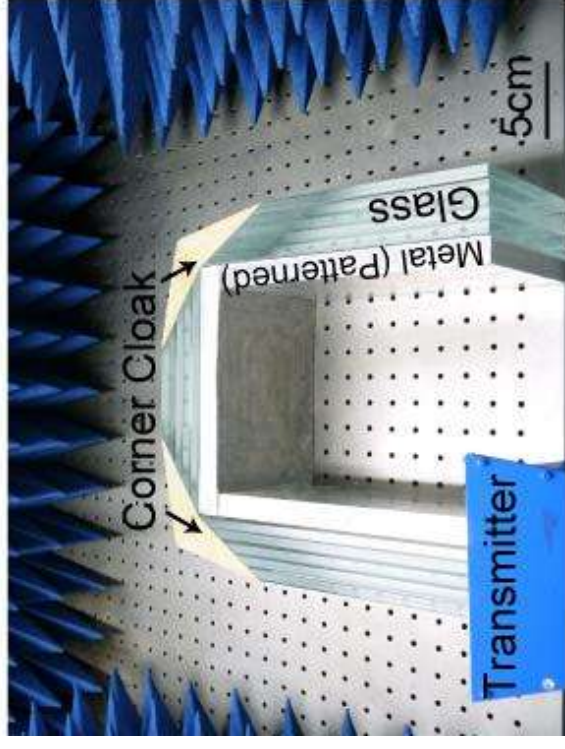
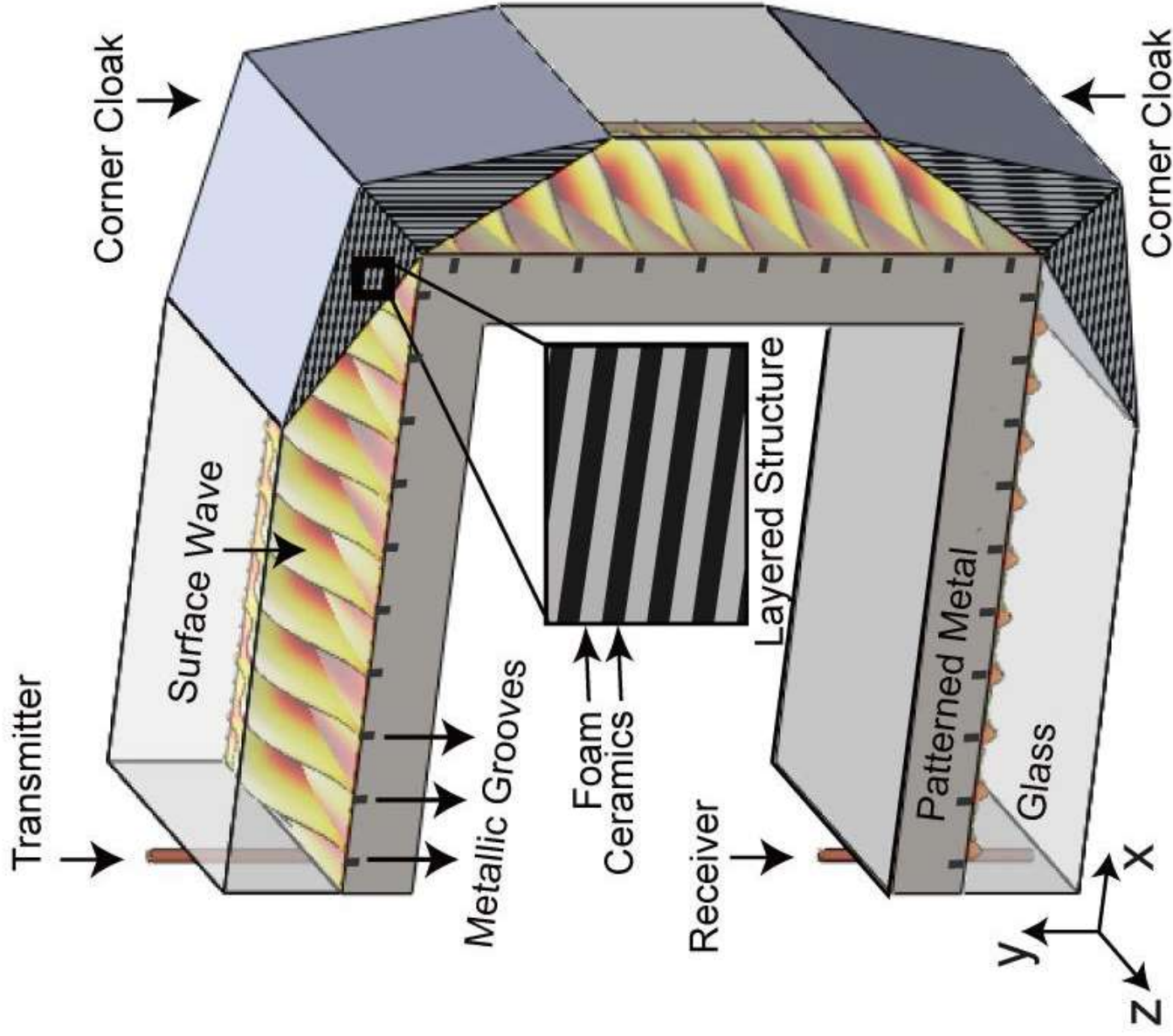
or

Air/Germanium at optical

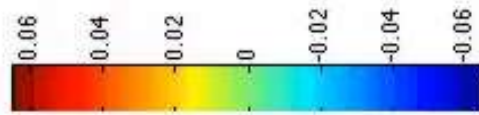
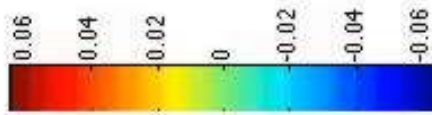
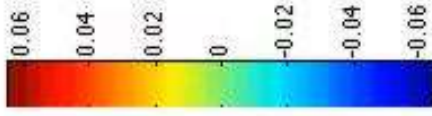




# Corner cloaks

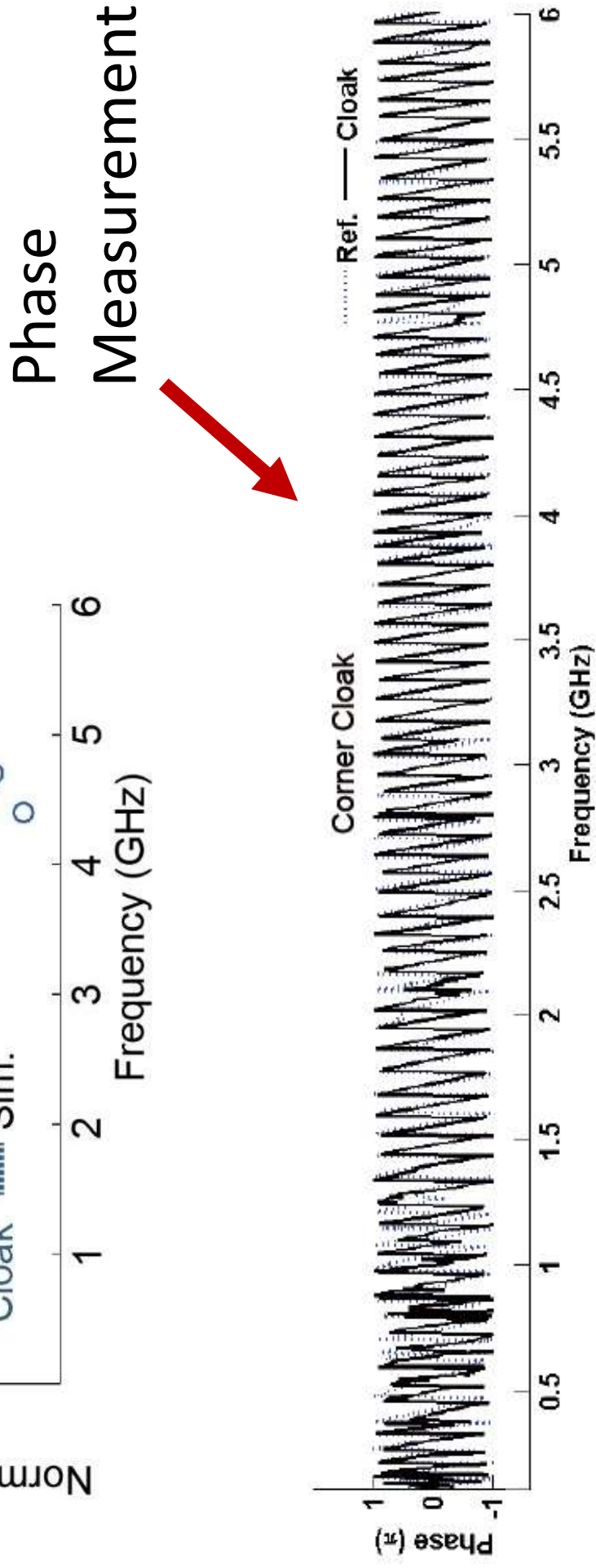
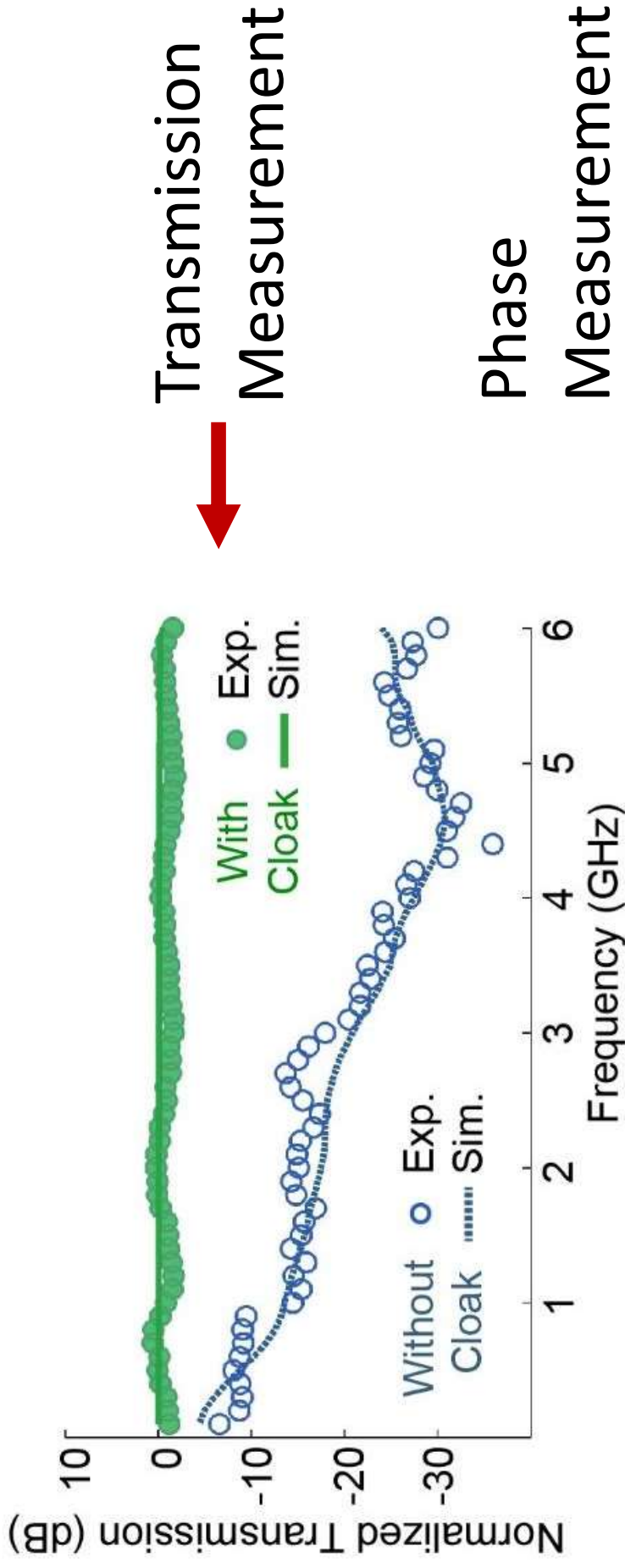


0.32ns



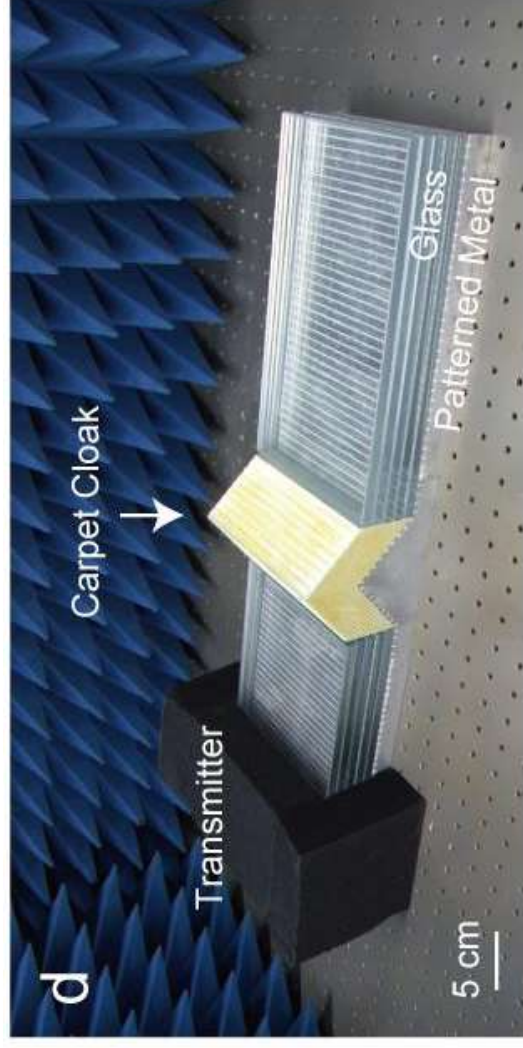
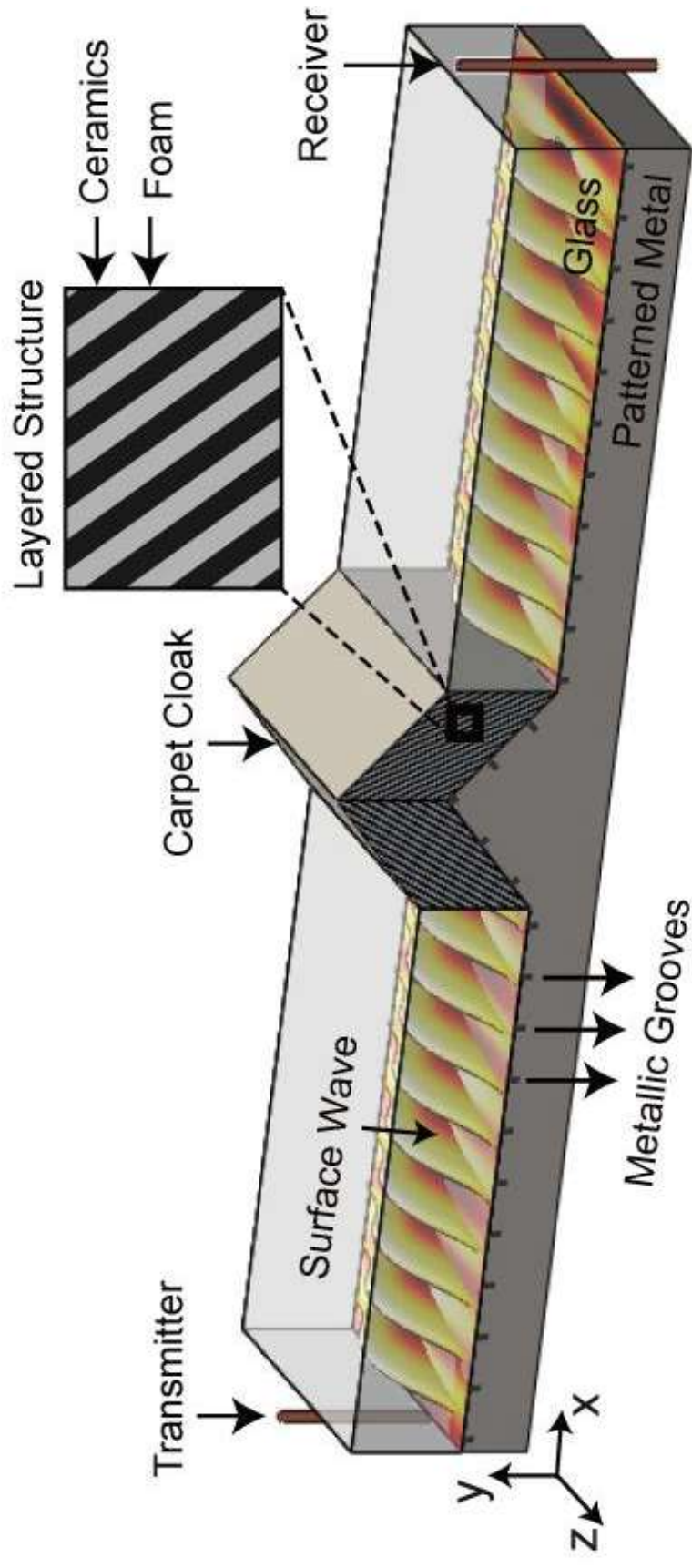
Click here for video: <https://youtu.be/eMXreqx7Yfo>

# Corner cloaks

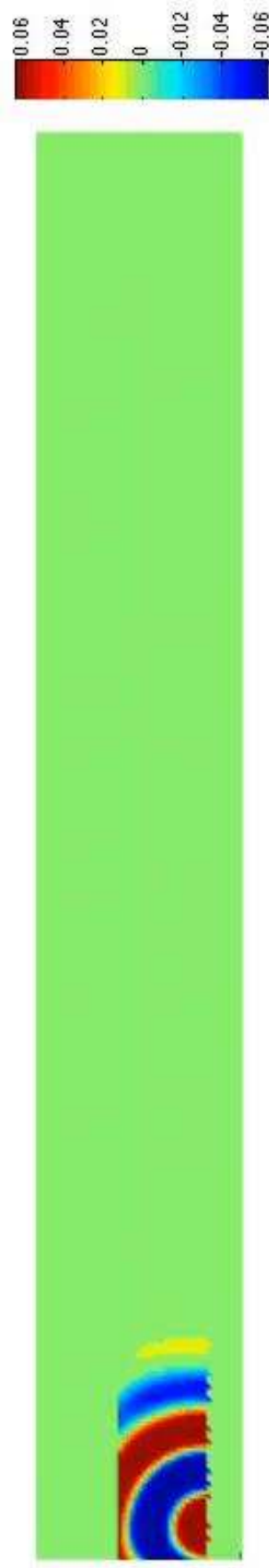
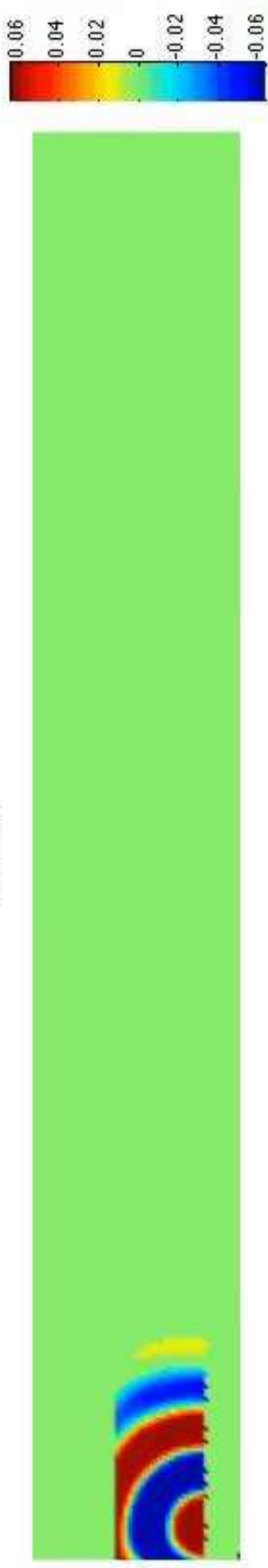




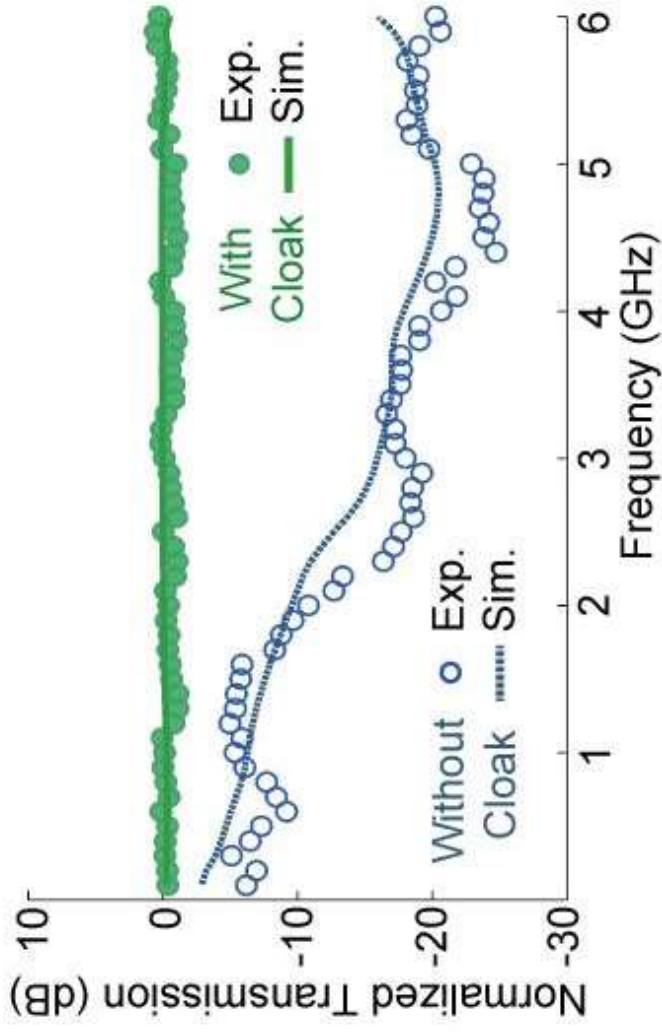
# Carpet cloak



0.32ns

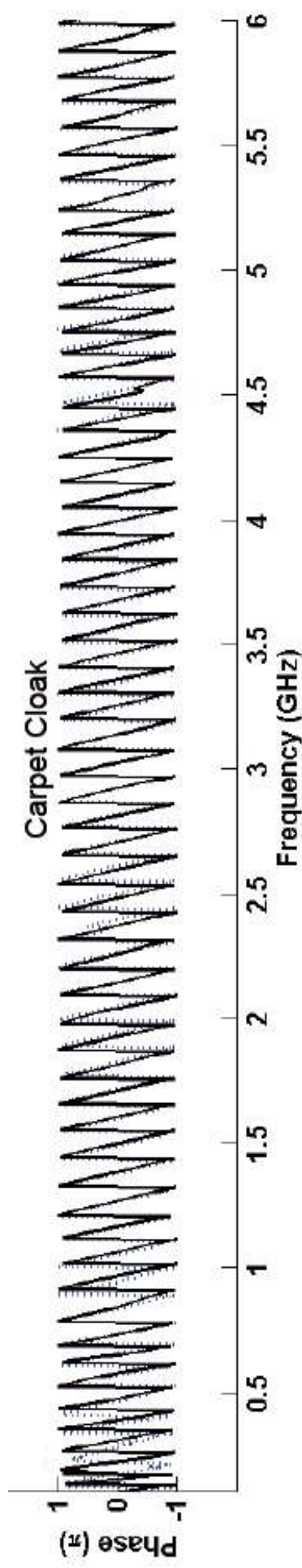


# Carpet cloak



Transmission  
Measurement

Phase  
Measurement





# Thanks!

## Broadband surface-wave transformation cloak

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Contributed by John D. Joannopoulos, May 7, 2015 (sent for review February 27, 2015; reviewed by Demetrios Christodoulides and Michelle L. Povinelli)